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Comparative Analysis of Direct Torque Control and Fuzzy Logic Control of Three Phase Induction Motor

Maruti Nandan Mishra
Department of Electrical Engineering, Manipal University, Jaipur, India
E-mail: marutinandan.mishra@jaipur.manipal.edu

Abstract

Induction motors are the starting point to design an electrical drive system which is widely used in many industrial applications. With the joint progress of the power electronics and numerical electronics it is possible today to deal with the axis control with variable speed in low power applications. The direct torque control scheme provides excellent properties of regulation without rotational speed feedback. In this paper, Induction motor has been simulated in stationary d-q reference frame and its free acceleration characteristics are drawn. To reduce the ripple in current and voltage waveform space vector PWM method and fuzzy logic control is also implemented.

Keywords: *Direct torque control, space vector PWM, VSI, IMD (induction motor drives), fuzzy logic controller*

INTRODUCTION

Over the past decades DC machines were used on large scale for variable speed applications because of the decoupled control of flux and torque which can be obtained by armature and field current control respectively. DC drives are useful in many aspects as high starting torque and ease of control. In spite of all these advantages DC motor drives suffer from one major drawback which is the presence of mechanical commutator and brush. The concept of DTC spread widely and quickly than vector control in industry applications. The most frequently used static power converter in DTC drive is VSI.

When resistance of stator winding is neglected then stator flux is integral of the applied voltage. Therefore, for short period of time the change in stator flux is proportional to the voltage available. The time constant of rotor of induction motor is normally high value hence flux linkage of rotor will change slowly with respect to the stator flux linkage [1–5]. The active voltage space vector of forward group is applied when the required torque is to be increased and this causes the torque angle increase. Similarly, backward or zero active voltage space vector is applied when the torque requirement is less than as present and this causes the torque angle to be decreased. Hence, this can be concluded that the torque can be controlled directly and increased and decreased directly by rotating stator flux linkage space vector at the appropriate location. This is why the control scheme is called DTC [5–12].

DIRECT TORQUE CONTROL

Field oriented control is a good control technique but the major drawback is that it depends on accurate knowledge of the motor parameters [13– 19]. A more attractive control technique consists first in removing the machine stator flux and electromagnetic torque in the stationary reference frame from terminal measurements. The governing equation for torque for this scheme is due to the interaction of stator and rotor fields [20 –25]. Torque and stator flux linkages are computed from measured stator voltages and current. An optimal voltage vector for the switching of VSI is selected among the six nonzero voltage vectors and two zero voltage vectors by the hysteresis control of stator flux and torque [26–31].

A three-phase VSI has eight possible combinations of six switching devices. The six switches have a well-defined state: ON or OFF in each configuration. So, all the possible configurations can be identified with three bits (Sa, Sb, Sc), one for each inverter leg. The bit is set to 1 if the top switch is closed and to 0 when the bottom switch is closed. The stator voltage space vector is

$$\overline{V_S} = \frac{2}{3}E\left[S_a + e^{j\frac{2\pi}{3}}S_b + e^{j\frac{2\pi}{3}}S_c\right] \qquad (3.1)$$

The electromagnetic torque produced due to interaction of stator and rotor flux is given by the following equation:

$$T_e = \frac{3}{2}\left(\frac{P}{2}\right)\frac{L_m}{L_s' L_r}\overline{\Psi_s} \cdot \overline{\Psi_r} \qquad (3.4)$$

From the above it is clear that torque varies directly as angle between stator flux and rotor flux, i.e., γ. So, in order to obtain high dynamic performance it is required to vary γ quickly. Assuming the rotor is rotating in anticlockwise direction continuously and stator flux lies in sector k, the active forward voltage vectors (Vs, k+1 and Vs, k+2) are applied to increase γ so as the torque Te. The radial voltage vectors (Vs, k and Vs, k+3) are used to decrease γ and Te. By applying the reverse active voltage vectors (Vs, k-1 and Vs, k-2) torque can be decreased rapidly. The two zero voltage vectors (Vs, 0 and Vs, 7) are applied to maintain the flux constant ideally and to decrease the torque slightly [32–38].

FUZZY LOGIC CONTROL OF INDUCTION MOTOR USING DTC

The block diagram used for implementation of DTFC of IMD is shown in Figure 1. A voltage source inverter supplies the motor and instantaneous values of the stator flux and torque are calculated from stator variable by using a closed loop estimator. The fuzzy logic controller is characterized as follows:

- Seven fuzzy sets for input and output variables.
- Fuzzification using continuous universe of discourse.
- Implication using Mamdani's 'min' operator.
- De-fuzzification using centroid method.

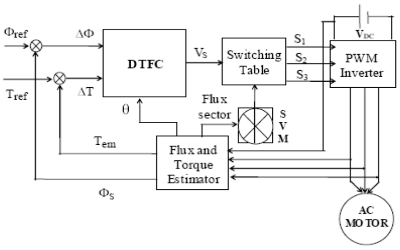


Fig. 1: *Block Diagram of Proposed FLC for IMD.*

The fuzzy sets are defined with triangular membership functions. In fuzzy membership function there are two input variable and each input variable have seven linguistic values. The fuzzy control rules are shown in Table.

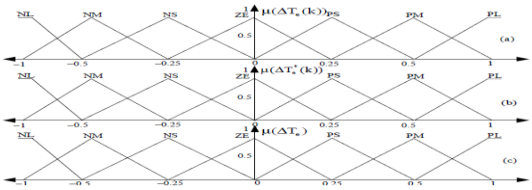
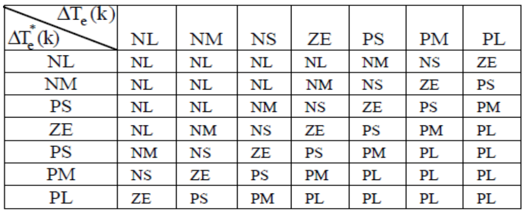


Fig. 2: *The Fuzzy Membership Functions of Input Variables (a) Torque Error, (b) Change in Torque Error and (c) Output Variable.*

Table 1: *Fuzzy Logic Control Rules.*



$\Delta T_e(k)$ $\Delta T_e^*(k)$	NL	NM	NS	ZE	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	ZE
NM	NL	NL	NL	NM	NS	ZE	PS
PS	NL	NL	NM	NS	ZE	PS	PM
ZE	NL	NM	NS	ZE	PS	PM	PL
PS	NM	NS	ZE	PS	PM	PL	PL
PM	NS	ZE	PS	PM	PL	PL	PL
PL	ZE	PS	PM	PL	PL	PL	PL

SIMULATION RESULTS AND DISCUSSION

Direct torque control algorithm of Induction motor drive has been simulated using MATLAB/Simulink 7.10.0 (R2010a). The induction motor is fed by an IGBT PWM voltage source inverter consists of Universal Bridge Block. Flux and torque references are produced using speed control loop which employs proportional integral control. The model is run for typical conditions of reference speed and applied torque value. The complete Simulink model of DTC scheme of IM for a 200HP, 460V, 60Hz, 4pole, 3-phase induction motor is used for the simulation.

Case 1: t = [0, 1]; speed = [500, 0]

t = [0, 0.2, 0.5, 1.5];

Torque = [0, 200, 792, -792]

Using conventional DTC

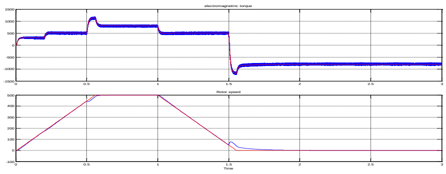


Fig. 3(a): *Plots of Electromagnetic Torque and Speed using Conventional DTC.*

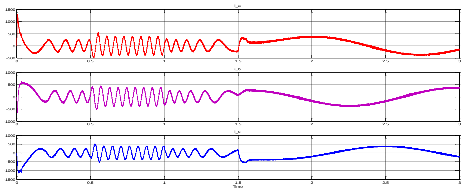


Fig. 3(b): *Plots of Stator Current using Conventional DTC.*

At t=0 sec speed is set to 500 rpm and torque is set to zero value. Now, at t=0.2 sec a load torque of 200 N-m is applied while the motor is still accelerating to its final value. The electromagnetic torque increases to its maximum value at t=0.5 sec and then stabilizes to at 800 N-m. At t=0.5 sec speed set point is changed to 0 rpm, speed decreases to 0 rpm with deceleration and finally stabilizes to zero value. The variation in stator current, electromagnetic torque and rotor speed is shown in Figure 3(a) and 3(b).

t = [0, 1]; speed = [500, 0]

t = [0, 0.2, 0.5, 1.5];

Torque = [0, 200, 792, -792]

DTC using SVPWM:

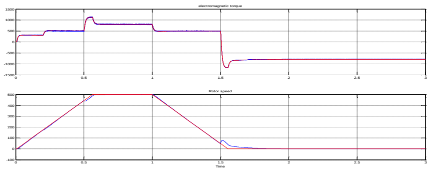


Fig. 4(a): *Plots of Electromagnetic Torque and Speed using SVPWM DTC.*

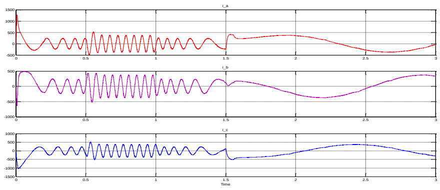


Fig. 4(b): *Plots of Stator Current using SVPWM DTC.*

From Figure 4(a) and 4(b) it was observed that the variation in waveform remains same but ripples in output waveforms are substantially reduced. The ripples in electromagnetic torque are removed. At t = 1 sec speed reference is set to zero value and hence the rotor speed is finally stabilizes to zero value following the deceleration. The plots are shown in 4(a) and 4(b).

t = [0, 1]; speed = [500, 0]

t = [0, 0.2, 0.5, 1.5];

Torque = [0, 200, 792, -792]

DTC using fuzzy logic controller:

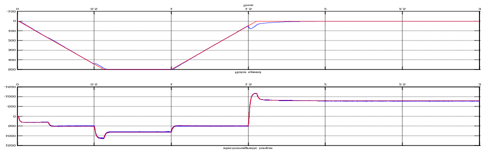


Fig. 5(a): *Plots of Electromagnetic Torque and Speed using FLC DTC.*

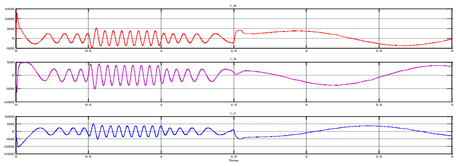


Fig. 5(b): *Plots of Stator Current using FLC DTC.*

From the diagram we can conclude that the waveform of the IMD using fuzzy logic control is comparable to the control method using SVPWM. Ripples in the waveform is also reduced which is shown in 5(a) and 5(b). As the loading condition is changed the variation in stator current, electromagnetic torque and rotor speed is following the SVPWM method and the ripples in waveform is substantially reduced.

Case 2: t = [0, 1]; speed = [500, 100]

t = [0, 0.2, 0.5, 1.5]; torque = [0, 200, 500, 700]

Using conventional DTC:

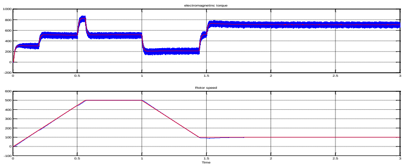


Fig. 6(a): *Plots of Electromagnetic Torque and Speed using DTC under Different Loading Conditions.*

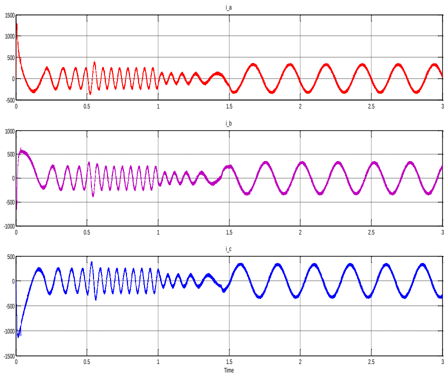


Fig. 6 (b): *Plots of Stator Current using Conventional DTC under Different Loading Conditions.*

At t=0 sec speed is set to 500 rpm and torque is set to zero value. Now, at t=0.2 sec a load torque of 200 N-m is applied while the motor is accelerating and at t = 0.5 sec a load at 500 N-m is applied due to which the speed is still accelerating and stabilizes to its final value. The electromagnetic torque increases to its maximum value at t=0.55 sec and then again at t = 1.5 sec load torque is changed to 700 N-m hence the final value of load torque is stabilizes to 700 N-m. At t = 1sec speed set point is changed to 100 rpm and hence finally speed value sets at 100 rpm. The variation in stator current, electromagnetic torque and rotor speed is shown in Figure 6(a) and 6(b).

t = [0, 1]; speed = [500, 100]

t = [0, 0.2, 0.5, 1.5]; torque = [0, 200, 500, 700]

DTC using SVPWM:

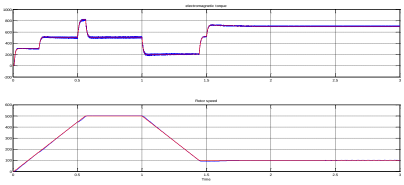


Fig. 7(a): *Plots Electromagnetic Torque and Speed using SVPWM under Different Loading Conditions.*

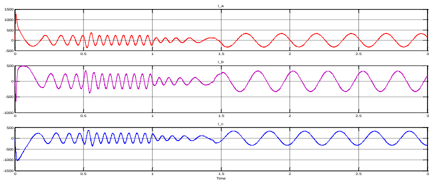


Fig. 7(b): *Plots Stator Currents using SVPWM under Different Loading Conditions.*

From Figure 7(a) and 7(b) it was observed that the variation in waveform remains same but ripples in output waveforms are substantially reduced. The ripples in electromagnetic torque are removed. At t = 1 sec speed reference is set to 100 value and hence the rotor speed is finally stabilizes to 100 value following the deceleration.

t = [0, 1]; speed = [500, 100]

t = [0, 0.2, 0.5, 1.5]; torque = [0, 200, 500, 700]

DTC using fuzzy control:

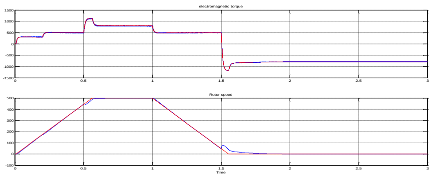


Fig. 8(a): *Plots of Electromagnetic Torque and Speed using Fuzzy Logic Controller.*

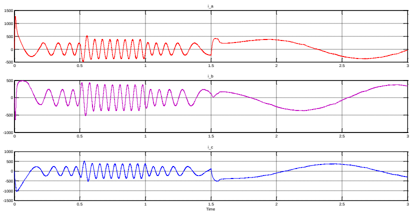


Fig. 8(b): *Plot of Stator Current of DTC using Fuzzy Logic Controller.*

From the diagram we can conclude that the waveform of the IMD using fuzzy logic control is comparable to the control method using SVPWM. Ripples in the waveform is also reduced which is shown in 8(a) and 8(b).

Case 3:

t = [0]; speed = [500]

t = [0, 0.5]; Torque = [0, 500]

Using conventional DTC:

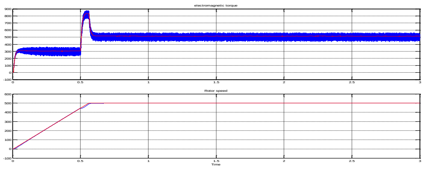


Fig. 9(a): *Plots of Torque and Rotor Speed for a Constant Speed using Conventional DTC.*

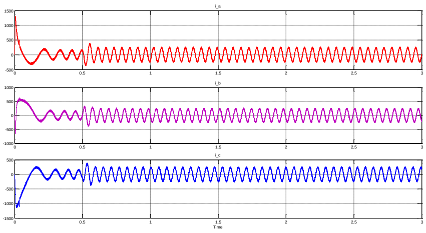


Fig. 9 (b): *Plots of Stator Current for a Constant Speed using Conventional DTC.*

t = [0]; speed = [500]

t = [0, 0.5]; Torque = [0, 500]

DTC using SVPWM:

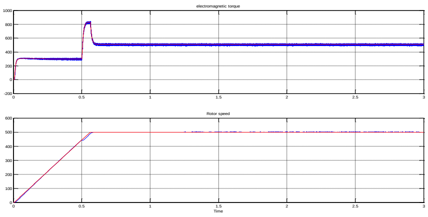


Fig. 10 (a): *Plots of Torque and Speed for a Constant Speed using SVPWM DTC.*

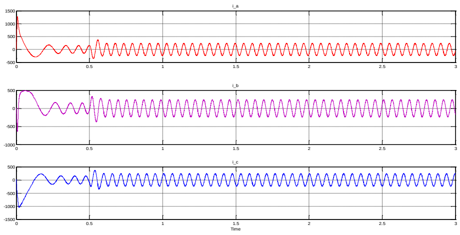


Fig. 10 (b): *Plots Stator Current for a Constant Speed using SVPWM DTC.*

t = [0]; speed = [500]
t = [0, 0.5]; Torque = [0, 500]
DTC using FLC:

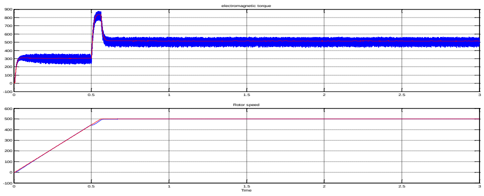


Fig. 11 (a): *Plots of Torque and Speed for a Constant Speed using FLC DTC.*

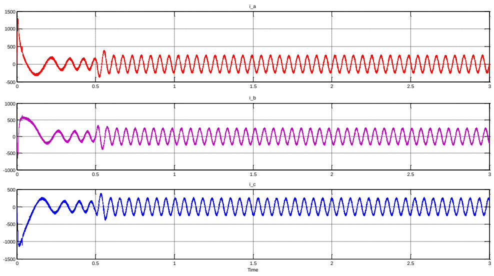


Fig. 11(b): *Plots Stator Current for a Constant Speed using FLC DTC.*

From the diagram we can conclude that the waveform of the IMD using conventional DTC, SVPWM and fuzzy logic control that at t = 0.5 sec a load of 500 N-m is applied due to which stator current fluctuates for a cycle and then comes to a steady state value. After then the motor runs with a constant speed of 500 rpm. The variation in stator current, electromagnetic torque and rotor speed is shown in the Figures 9 to 11.

CONCLUSION

For any IM drives, direct torque control is one of the best controllers proposed so far. It allows decoupled control of motor stator flux and electromagnetic torque. From the analysis it is proved that, this strategy of IM control is simpler to implement than other vector control methods as it does not require pulse width modulator and co-ordinate transformations. But it introduces undesired torque and current ripple. DTC scheme uses stationary d-q reference frame with d-axis aligned with the stator axis.

Stator voltage space vector defined in this reference frame control the torque and flux. The ripple in stator current and torque are substantially reduced by using Fuzzy logic control and SVPWM.

REFERENCES

1. Depenbrock, M. Direct self-control (DSC) of inverter fed induction motors. *IEEE Trans. on Power Elect*. 1988; 3(4): 420-429p.
2. Holtz, J., Khambadkone, A. vector controlled induction motor drive with a self-commissioning scheme. *IEEE Trans. on Ind. Elect.* 1991; 38: 322-327p.
3. Xu, X., Novotny, D. W. Selection of the flux reference for induction machine drive in the field weakening region. *IEEE Trans. Ind. Application.* 1992; 28: 1353-1358p.
4. Habetler, T. G., Porfumo, F., Pastroelli, M., Tolbert, L. M. Direct torque control of induction machine using space vector modulation. *IEEE Trans. Ind. Appl.* 1992; 28: 1045-1053p.
5. Holtz, J. Pulse width modulation: A survey. *IEEE Trans. Ind. Elect.* 1992; 39: 410-420p.
6. Holtz, J., Khamabdkone, A. M., Lotzkat, W. On continuous control of PWM inverters in the over modulation range including the six step mode. *IEEE Trans. Power Electronics*. 1993; 8: 546-553p.
7. Thomas G. Habetler, Francesco Profumo, Michele Pastorelli, Leon M. Tolbert. Direct torque control of induction motor using space vector modulation. *IEEE Trans. Power Electronics.* 1993; 8(4): 546-553p.
8. Pagni, R. Poluzzi, G. Rizzotto, M. Presti. Automatic synthesis, analysis and implementation of fuzzy controller. *In Proc. of International Conference on Fuzzy Systems, IEEE.* 1993, 1: 105-110p.
9. Abe, T., Habetler, T. G., et.al Evaluation of a high performance induction motor drive using direct torque control. *IEEE, power conversion conference.* 1993; 10: 444-449p.
10. Levi, E. Impact of iron loss on behavior of vector controlled induction machines. *IEEE Ind. App. Soc. Ann. Mtg.* 1994; 1: 74-80p.
11. Krishnan, R. Permanent magnet synchronous motor and brushless DC drives. CRC press, Taylor & Fransis group; 2010.
12. Mohan. N. Electric drives an integrative approach. 2nd Edition. MNPERE, Minneapolis; 2001.
13. Bose, B. K. Modern power electronics and AC drives. Low Price Edition; 2009.
14. Krishnan, R. Electric motor drives: modeling analysis and control. Prentice Hall; 2001.

15. Mir, S. A., Elbuluk, M. E., Zinger, D. S. Fuzzy implementation of direct self-control of induction machines. *IEEE Trans. Ind. Appl.* 1994; 30: 729-735p.
16. Levi, E. Impact of iron loss on behavior of vector controlled induction machines. *IEEE Trans. Ind. App.* 1995; 31: 1287-1296p.
17. Grotstollen, H., Wiesing, J. Torque capability and control of a saturated induction motor over a wide range of flux weakening. *IEEE Trans. Ind. Elect.* 1995; 42: 374-381p.
18. Kerkman, R. J., Leggate, D., Seibel, B. J., Rowan, T. M. Operation of voltage source inverters in the over-modulation region. *IEEE Trans. Ind. Elect.* 1996; 43: 132-140p.
19. Tiitinen, P., Surandra, M. The next generation motor control method, direct torque control. *IEEE conference on power electronics, drives and energy systems for industrial growth.* 1996; 1: 37-43p.
20. Blasko, V. A hybrid PWM strategy combining modified space vector and triangle comparison methods. *IEEE, Power Electronics Specialist Conference,* 1996; 2: 1872-1878p.
21. Meynard, T. A., Fadel, M., Aouda, N. Modeling of multilevel converters. *IEEE Trans. Ind. Elec.* 1997; 4: 356-364p.
22. James N. Nash. Direct torque control, induction motor vector control without an encoder. *IEEE Trans. on Industry Applications.* 1997; 33(2): 333-341p.
23. Lee, D. C., Lee, G. M. A novel over-modulation technique for space vector PWM inverter. *IEEE Trans. Power Elect.* 1998; 13: 1144-1151p.
24. C. Lascu, I. Boldea, F. Blaabjerg. A modified direct torque control for induction motor sensorless drive. *IEEE* 1998; 1: 415-422p.
25. D. Casadei, G. Serra, A. Tani. The use of matrix converters in direct torque control of induction machines. *IEEE.* 1998; 2: 744-749p.
26. P. C. Costa, Adriano S. C., M. F. Chouzal, C. A. Martins. Direct torque control- frequency analysis. *IEEE.* 1998; 21-23p.
27. Kang, J., Li, Y. Virtual vectors based predictive control of torque and flux of induction motor for minimum ripple and constant switching frequency. *IEEE Trans. on Ind. Appl.* 1999; 35: 1076-1082p.
28. Tolbert, L. M., Peng, F. Z., Habetler, T. Multilevel converters for large electric drives. *IEEE Trans. on Ind. Appl.* 1999; 35: 36-44p.

29. Hoang Le-Huy. Comparison of field oriented control and direct torque control for induction motor drives. *IEEE*. 1999; 1245-1252p.
30. Jun-Koo-Kang, Dae-Woong Chu, Seung-Ki Sul. Direct torque control of induction machine with variable amplitude control of flux and torque hysteresis bands. *IEEE*. 1999; 640-642p.
31. C. G. Mei, S. K. Panda, Jx Xu, Kw Lim. Direct torque control of induction motor variable switching sectors. *International Conference on Power Electronics and Drive system, IEEE*. 1999; 80-85p.
32. Arias, A., Romeral, J.L., Aldabas, E. Jayne. Fuzzy logic direct torque control. *ISIE'00. IEEE International Symposium on Industrial Electronics*. 2000; 1: 253-258p.
33. Victor Perelmuter. Three level Inverters with direct torque control. IEEE. 2000; 3: 1368-1374p.
34. Arias, A., Romeral, J.L., Aldabas, E. Jayne. Improving direct torque control by means of fuzzy logic. *SAAEI'00, Seminario Anual de Automática, Electrónica Industrial e Instrumentación*. 2000; 197-200p.
35. R.Toufouti S.Meziane, H. Benalla. Direct torque control for induction motor using fuzzy logic. *ACSE Journal*. 2000; 6: 611-617p.
36. Briz, F., Diez, A., Degner. M. W., Lorenz, R. D. Current and flux regulation in field weakening operation of induction motors. *IEEE Trans. on Ind. Appl*. 2001; 37: 42-50p.
37. Harnefor, L. Pietilainen, K., Gertmer, L. Torque-maximizing field-weakening control: design, analysis, and parameter selection. *IEEE Trans. on Ind. Elect*. 2001; 48: 161-168p.
38. Zhou, K. And Wang, D. Relationship between space vector modulation and three phase carrier based PWM: A comprehensive analysis. *IEEE Trans. on Ind. Elect*. 2002; 49: 186-196p.